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ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS: A SURVEY

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ABSTRACT

Wireless Sensor Networks (WSNs) consist of a large number of sensor nodes capable of sensing, computation and communications. WSNs have become an effective and attractive choice for various applications because of low cost, ease of deployment, adhoc and multifunctional capabilities. Various protocols have specially designed for the Wireless Sensor Networks in terms of routing, power management and data dissemination. The focus of the various routing protocols might differ depending on the application and network architecture. In the proposed paper, an attempt is made to present the state-of-the-art routing techniques and the design challenges for various routing protocols in WSNs. The main focus is to discuss and evaluate the performance of different routing protocols with the help of important metrics and parameters. On the basis of simulated results from empirical study and literature review recommendations are made for better selection of protocol for the given design conditions.

***KEYWORDS:** WSN, Routing Protocols, Sensors, Energy Efficiency, Clustering, Wireless Communications*

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INTRODUCTION

Wireless Sensor Networks have emerged as an important research area with an overwhelming effect on practical and real time applications.WSN consists of hundreds to thousands of sensor nodes of low-power, multi-functional, operating in an unattended environment having sensing, computation and communication capabilities. Advances in the wireless communication technologies, computation technologies and integration of Micro-Electro-Mechanical System (MEMS), made it possible to develop various WSNs.

WSN consists of small devices called sensing nodes, which collect information by cooperating with each other and consist of data processing (CPU), memory (for data storage), battery (for energy) and transceiver (for receiving and sending signals/data from one node to another). The size and number of sensor nodes varies with the applications and basically the cost of networks depends upon the parameters like memory size, processing speed and battery. For example, in military or surveillance applications it might be microscopically small.

In recent days, Wireless Sensor Networks are finding wide applications in the commercial and industrial areas such as environmental, habitat, healthcare, process monitoring and surveillance. In the military area, we can use wireless sensor networks to monitor many activities. The sensor nodes in WSNs sense if an event is triggered and send the information to the base station (called sink) by communicating with other nodes. The importance and use of wireless sensor networks is increasing day by day and at the same time it faces the problem of energy constraints in terms of limited battery lifetime. In WSNs the only source of life for the sensor nodes is the battery and each node depends on energy for its activities, which has become a major issue in wireless sensor networks. The failure of one node can interrupt the entire system or network. Every sensing node in the network can be in any

of the modes (i) active (for receiving and transmission activities), (ii) idle and (iii) sleep modes. In active mode, nodes consume energy when receiving or transmitting data. In idle mode, the nodes consume almost the same amount of energy as in active mode, while in sleep mode, the nodes shutdown the radio to save the energy.

In surveillance applications, it is undesirable and difficult to replace the batteries that are depleted or drained of energy. Many researchers are working to find the power/energy efficient routing protocols for wireless sensor networks[1] in order to overcome energy efficiency problems. A protocol is said to have real-time support if and only if it is fast and reliable in its reactions to the changes that are occurring in the network. The delay in transmission of data from one node to another sensing node should be short, which leads to a faster response.

CHARACTERISTICS OF WIRELESS SENSOR NETWORKS

A Wireless Sensor Networks are different from other popular wireless communication networks like cellular network, wireless local area network (WLAN) and Bluetooth in many ways. WSNs have much more nodes in a network, distance between the neighboring nodes is much shorter and application data rate is much lower as compared to other wireless networks[1]. Due to these characteristics, power consumption in a sensor network should be minimized.

Table 1: Comparison between Various Wireless Networks

S. No	Types	No. of Nodes	Range	Data Rate	Mobility	Power	Redundancy
1	Cellular	Large	Long	Medium	High	High	Low
2	WLAN	Small	Medium	High	Medium	Medium	Low
3	Bluetooth	Small	Short	Medium	Low	Low	Low
4	WSN	Large	Very Short	Low	Low	Very Low	High

The cost of the complete sensor network depends upon the cost of each sensor nodes used in the network. It is economical to use tiny sensor nodes which make it easier for a sensor to be embedded in the working environment. Redundant data is inevitable in WSNs as multiple sensors sense similar information and this sensed data need to be aggregated to decrease the number of transmissions in the network, reducing bandwidth usage and eliminating unnecessary energy consumption in both transmission and reception.

ADVANTAGES OF WIRELESS SENSOR NETWORKS

The importance of WSNs has rapidly increasing and they are becoming integral part of our lives, because of their various advantages such as Ease of deployment, Extended range of sensing, Improved lifetime, Fault tolerance, Improved accuracy, Lower cost, Actuation and the Collaborative objective

CHALLENGES OF WIRELESS SENSOR NETWORKS

For designing the applications for wireless sensor networks, it is essential to understand various design factors concerned with applications. The proposed protocols and algorithms of the traditional wireless adhoc networks are not well suited for the application requirements of the sensor networks even though WSNs share some commonalities with existing wireless adhoc networks but they pose a number of technical challenges which are different from traditional wireless adhoc networks [1][2]. Main challenges of sensor networks when compared with the traditional networks are in terms of energy of sensing nodes, redundancy, system life time, scalability, adaptability, application awareness, lack of global identification, database for the storage, search and retrieval, data centric processing, production cost, node deployment, In-network processing, latency and fault tolerance.

CLASSIFICATION OF ROUTING PROTOCOLS

Routing is the process of using the best possible paths from the source to the destinations in a given network. The routing process uses the routing tables which maintain a record of the various routes to network destinations. In the router's memory, routing tables are constructed which is an important factor for the building the efficient and effective routing. Most of the routing algorithms use only one path at a time whereas the multipath routing techniques use multiple alternative paths. Routing[2] in WSN's differs from conventional networks in numerous various ways such as sensor nodes may fail making the wireless links unreliable and routing protocols have to meet energy requirements of the sensor nodes. Routing protocols in WSNs can be classified based on the method used to acquire the information, maintain the information and also on the basis of path computation.This classification of protocol is based on how the source node finds a route to a destination node [3].

Proactive Protocols

Proactive routing protocols[2] are table driven protocols which maintain accurate routing tables of all network nodes using periodic dissemination of routing information and all routes are computed before their usage. Proactive routing protocols can be used both in flat and hierarchal structured networks.

Reactive Protocols

Reactive routing protocols [2] do not maintain the information of all the nodes of a network and based upon demand the route is established between source and destination by using the route query before route establishment. Thèse stratégies are different by two ways by re-establishing and re-computing the path in case of nodes failure and by reducing communication overhead caused by congestion in the networks

Hybrid Protocols

Hybrid routing strategies[2] uses both proactive and reactive routing strategies for the larger networks. It uses clustering technique which makes the network stable and scalable. The complete network is divided into many clusters which are maintained dynamically if a node is added or leave a particular cluster. This protocol uses proactive technique when routing is needed within clusters and reactive technique when routing is needed across the clusters.

Routing protocols for WSN are classified according to the nature of WSN operation and its network architecture. WSN routing protocols can be subdivided into two broad categories, network architecture based routing protocols and operation based routing protocols [2].

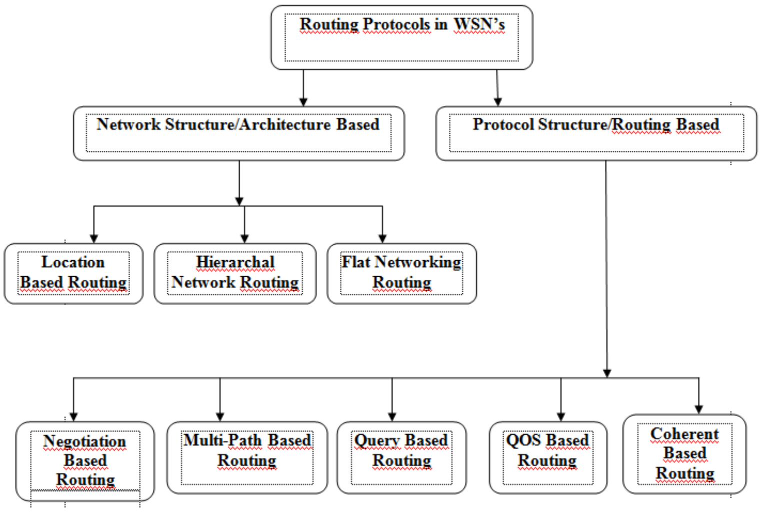

Figure 1: Classification of Routing Protocols in Wireless Sensor Networks

Architecture Based Routing Protocols

Architecture Based Routing Protocols[1][2] are classified based upon the structure of network and are further divided into three subcategories according to their functionalities[3]

A. Flat-based routing B. Hierarchical-based routing C. Location-based routing

- **Flat-Based Routing**

Flat-based routing[1][2] is required for the networks which consist of a large number of nodes where every node plays same role. Data centric routing approach[4] is used in which base station sends query to a group of particular nodes in a region and waits for response as it is not possible to assign a particular identity to each and every node.

Examples of Flat-based routing protocols [1] are

- Energy Aware Routing (EAR)
- Directed Diffusion (DD)
- Sequential Assignment Routing (SAR)
- Minimum Cost Forwarding Algorithm (MCFA)
- Sensor Protocols for Information via Negotiation (SPIN)
- Active Query forwarding In sensor network (ACQUIRE)

- **Hierarchical-Based Routing (Cluster Based Routing)**

Hierarchical-based routing [6] is energy efficient method in which high energy nodes are randomly selected for processing and sending data while low energy nodes are used for sensing and send information to the cluster heads. This property of hierarchical-based routing contributes greatly to the network scalability, lifetime and minimum energy. Examples of hierarchical-based routing protocols are [9]

  - Hierarchical Power-Active Routing (HPAR)
  - Threshold sensitive Energy Efficient sensor Network protocol (TEEN)
  - Low Energy Adaptive Clustering Hierarchy (LEACH)
  - Power Efficient Gathering in Sensor Information Systems (PEGASIS)
  - Minimum Energy Communication Network (MECN)
- **Location-Based Routing**

In an area of interest sensor nodes are scattered randomly and mostly known by the geographic position where they are deployed by means of GPS [5]. The distance between nodes is estimated by the signal strength received from those nodes and coordinates are calculated by exchanging information between neighboring nodes.

Location-based routing networks[7] are

  - Sequential Assignment Routing (SAR)
  - Ad-hoc Positioning System (APS)
  - Geographic Adaptive Fidelity (GAF)
  - Greedy Other Adaptive Face Routing (GOAFR)
  - Geographic and Energy Aware Routing (GEAR)
  - Geographic Distance Routing (GEDIR)

Operation Based Routing Protocol Classification

WSNs applications are categorized according to their functionalities [8] and the routing protocols are also classified according to their operations to meet these functionalities to achieve optimal performance and to save the scarce resources of the network. Protocols classified to their operations are:

- Multipath routing protocols
- Query based routing
- Negotiation based routing
- QoS based routing
- Coherent routing
- **Multipath Routing Protocols**

These protocols provide multiple path selection [11] for a message to reach destination reducing delay and increasing network performance. Network reliability is achieved due to increased overhead and these protocols consume greater energy because of the network paths are kept alive by sending periodic messages.

Multipath routing protocols are [11]

- Multi path and Multi SPEED (MMSPEED)
- Sensor Protocols for Information via Negotiation (SPIN)

- **Query Based Routing Protocols**

This protocols works on sending and receiving queries for data. The destination node sends query of interest through the network and node with this interest matches the query and send back to the node which initiated the query. The queries are normally written in high level languages and they are classified as [13]

- Sensor Protocols for Information via Negotiation (SPIN)
- Directed Diffusion (DD)[15]
- COUGAR

- **Negotiation Based Routing Protocols**

High level data descriptors [9] are used to eliminate redundant data transmission through negotiation. These protocols make intelligent decisions either for communication or any other actions based on facts in the network. They are classified as

- Sensor Protocols for Information via Negotiation (SPIN)
- Sequential Assignment Routing (SAR)
- Directed Diffusion (DD)

- **Qos Based Routing Protocols**

In this type of routing, network needs to have a balance approach for the QoS.To achieve QoS, the cost function for the desired QoS also needs to be considered. Examples of such routing are [13]

- Sequential Assignment Routing (SAR)
- SPEED
- Multi path and Multi SPEED (MMSPEED)

- **Coherent Data Processing Routing Protocol**

In this routing scheme, nodes perform minimum processing on the raw data locally before sending for further processing to other nodes. Then it is sent to other nodes called aggregator for further processing known as aggregation [14]. Coherent data processing routing is used when energy-efficient [10] routing is required.

PERFORMANCE METRICS OF ROUTING PROTOCOLS

In order to evaluate the performance [12] of WSN's routing protocols, the following metrics were considered:

Table 2

S. No	Performance Metrics	Definition
1	**End-to-End Delay**	The average time interval between the generation of a packet in a source node and the successfully delivery of the packet at the destination node which counts all possible delays that can occur in the source and all intermediate nodes.
2	**Packet Delivery Fraction**	The ratio of the number of data packets successfully delivered to all destination nodes and the number of data packets generated by all source nodes.
3	**Routing Load**	The ratio of the number of routing messages propagated by every node in the network and the number of data packets successfully delivered to all destination nodes
4	**Number of Packets dropped**	The number of data packets that are not successfully sent to the destination during the transmission
5	**Jitter**	Jitter describes standard deviation of packet delay between all nodes
6	**Throughput**	The throughput metric measures how well the network can constantly provide data to the sink. Throughput is the number of packet arriving at the sink per millisecond
7	**Power consumption**	The total consumed energy divided by the number of delivered packet

COMPARISON OF ROUTING PROTOCOLS

The study of routing protocols in detail made it easy to evaluate each protocol depending upon the proposed factors. An evaluation is done on all the protocols depending upon their operation using the sensor nodes in the network.

Table 3: Routing Protocols Based on Latency, Scalability and Connection Adaptability

S.No	Characteristics Protocols	Latency	Scalability	Connection Adaptability
1	LEACH	Low when the network is small	High	Cluster Heads Lead the transmission
2	PEGASIS	High,if network density is high	High	Single node of the chain is responsible in transmission
3	SPIN	Moderate, if the network is large	Moderate	Data Shared with interested nodes,to reach sink
4	GEAR	Moderate, checks for drained nodes	Moderate	Calculates the least cost paths to reach sink
5	GAF	Moderate uses limited nodes	High	One node from the grid is used remaining go to sleep state
6	MECN	Moderate, few edges in the relay region	Low	Relay nodes are used to reach the sink
7	SAR	Low, Multipath exists	Moderate	Tree is designed from sink to nodes
8	SPEED	Low, always tries to reduce congestions	Moderate	Paths are built using least cost algorithms

Table 4: Routing Protocols Based on QOS, Traffic on Network and Network Power Usage

<table>
<tr><th rowspan="2">S.No</th><th>Characteristics</th><th colspan="2">Transmission Schemes</th><th colspan="3">Energy Awareness</th></tr>
<tr><th>Protocols</th><th>Flat</th><th>Multihop</th><th>Low</th><th>Medium</th><th>High</th></tr>
<tr><td>1</td><td>LEECH</td><td colspan="2">Multi Hop, cluster heads directly transmit to sink</td><td colspan="3">High Uses Clustering techniques to save energy</td></tr>
<tr><td>2</td><td>PEGASIS</td><td colspan="2">Multi path, only if the neighbors are at a larger distance than single hop</td><td colspan="3">High it forms chain using nodes to reach the base station</td></tr>
<tr><td>3</td><td>SPIN</td><td colspan="2">Multi Hop, Data shared on query based approach</td><td colspan="3">Moderate, the nodes which have energy resources only take part in transmission</td></tr>
<tr><td>4</td><td>GEAR</td><td colspan="2">Flat, once least path calculated is used until node failures occur</td><td colspan="3">Moderate, same path used until new path is calculated</td></tr>
<tr><td>5</td><td>GAF</td><td colspan="2">Multi Hop, uses nodes in virtual grids as intermediate nodes</td><td colspan="3">High, nodes use sleep discovery, awake states</td></tr>
<tr><td>6</td><td>MECN</td><td colspan="2">Multi Hop, sparse graph calculated and nodes chosen from relay regions</td><td colspan="3">Moderate, constructs sparse graph for every transmission</td></tr>
<tr><td>7</td><td>SAR</td><td colspan="2">Multi Hop, Trees are constructed either from node to sink or sink to node</td><td colspan="3">High, calculates the best path and does not deplete all the nodes in network</td></tr>
<tr><td>8</td><td>SPEED</td><td colspan="2">Multi Hop, if no node failures or congestions occur</td><td colspan="3">High Always uses multiple paths to transmit data</td></tr>
</table>

Table 5: Routing Protocols Based on QOS, Traffic on Network and Network Power Usage

S. No	Characteristics Transmission Scheme / Protocols	QoS	Traffic on Network	Network Power Usage
1	LEECH	Low	High, All Cluster heads start transferring data to sink	High
2	PEGASIS	Low	Low, Only one chain is formed by all nodes to transfer data	High
3	SPIN	Low	Low, less energy nodes avoided in transmission	Low
4	GEAR	Low	Moderate	Low
5	GAF	Low	Moderate	Low
6	MECN	Low	Low, selects nodes from relay region precisely	High
7	SAR	High	High, new routing tables be created every time to avoid	Low
8	SPEED	High	High, using backpressure rerouting avoided	Low

Table 6: Comparison of Different Routing Protocols in Terms of Network Lifetime & Resource Awareness

S.No	Parameter /Protocol	LEACH	TEEN	APTEEN	PEGASIS	SPIN	DD	RR	GEAR	GAF
1	**Network Lifetime**	Very Good	Very Good	Very Good	Very Good	Good	Good	Very Good	Good	Good
2	**Resource Awareness**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table.No.3, 4, 5 shows the characteristics of protocols with regard to Transmission Modes, Energy awareness Quality of Service (Qos), Traffic on network, Network Power Usage, used by the sensors during the protocol operation and the other factors like Network Lifetime and Resource awareness.

SUMMARY

We summarized the recent research results on data routing in WSNs shown in Table.no.6& 7 shows how different routing protocols fit under different category and also compare different routing techniques according to many metrics.

Table 7: Classification and Comparison of Routing Protocols in Wireless Sensor Networks

S.No	Routing Protocol	Classification	Mobility	Position Awareness	Power Usage	QoS	Negotiation based
1	SPIN	Flat	Possible	No	Limited	No	Yes
2	DIRECT DIFFUSION	Flat	Limited	No	Limited	No	Yes
3	RUMOUR ROUTING	Flat	Very Limited	No	N/A	No	No
4	GBR	Flat	Limited	No	N/A	No	No
5	MCFA	Flat	No	No	N/A	No	No
6	CADR	Flat	No	No	Limited	No	No
7	COUGAR	Flat	No	No	Limited	No	No
8	ACQUIRE	Flat	Limited	No	N/A	No	No
9	EAR	Flat	Limited	No	N/A	No	No
10	LEACH	Higherarchial	Fixed BS	No	Maximum	No	No
11	TEEN & APTEEN	Higherarchial	Fixed BS	No	Maximum	No	No
12	PEGASIS	Higherarchial	Fixed BS	No	Maximum	No	No
13	MECN & SMECN	Higherarchial	Fixed BS	No	Maximum	No	No
14	SOP	Higherarchial	No	No	Maximum	No	No
15	HPAR	Higherarchial	No	No	N/A	No	No
16	VGA	Higherarchial	No	No	N/A	No	Yes
17	SENSOR AGGREGATE	Higherarchial	No	No	N/A	No	No
18	TTDD	Higherarchial	Limited	No	N/A	No	No
19	GAF	Higherarchial	Yes	Yes	Limited	No	No
20	GEAR	Location	Limited	No	Limited	No	No
21	SPAN	Location	Limited	No	Limited	No	Yes
22	MFR, GEDIR	Location	Limited	No	N/A	No	No
23	GOAFR	Location	No	No	N/A	No	No
24	SAR	Location	No	No	N/A	Yes	Yes
25	SPEED	Qos	No	No	N/A	Yes	No

Table 8: Classification and Comparison of Routing Protocols in Wireless Sensor Networks

S.No	Routing Protocol	Data Aggregation	Localization	State Complexity	Scalability	Multi Path	Query Based
1	SPIN	Yes	No	Low	Limited	Yes	Yes
2	Direct Diffusion	Yes	Yes	Low	Limited	Yes	Yes
3	Rumour Routing	Yes	No	Low	Good	No	Yes
4	GBR	Yes	No	Low	Limited	No	No
5	MCFA	No	No	Low	Limited	No	No
6	CADR	Yes	No	Low	Limited	No	Yes
7	COUGAR	Yes	No	Low	Limited	No	Yes
8	ACQUIRE	Yes	No	Low	Good	No	Yes
9	EAR	No	yes	Low	Good	No	No
10	LEACH	Yes	yes	CHs	Good	No	No
11	TEEN & APTEEN	Yes	yes	CHs	Low	No	No
12	PEGASIS	No	Yes	Low	Low	No	No
13	MECN & SMECN	No	No	Low	Good	No	No
14	SOP	No	No	Low	Good	Yes	No
15	HPAR	No	No	Low	Good	No	Possible

Table 8: Contd.,							
16	VGA	Yes	Yes	CHs	Low	Possible	Possible
17	SENSOR AGGREGATE	Yes	No	Low	Good	No	No
18	TTDD	No	No	Moderate	Low	No	No
19	GAF	No	No	Low	Good	No	No
20	GEAR	No	No	Low	Limited	No	No
21	SPAN	No	No	Low	Limited	No	No
22	MFR, GEDIR	No	No	Low	Limited	No	No
23	GOAFR	No	No	Low	Good	No	No
24	SAR	Yes	No	Moderate	Limited	No	Yes
25	SPEED	No	No	Moderate	Limited	No	Yes

CONCLUSIONS

In the proposed paper, we presented a comprehensive survey of routing protocols in wireless sensor networks. Overall, the routing techniques are classified based on the network structure into three categories like flat, hierarchical, and location based routing protocols. Furthermore, these protocols are classified into Multipath, Query, negotiation, or QoS routing techniques depending on the protocol operation. We also highlighted the design tradeoffs between energy [16] and communication overhead savings in some of the routing paradigm, as well as the advantages and disadvantages of each routing technique. SPEED is one of the best routing protocols with low latency and energy conservative protocol. It always has low overhead with no congestions in the network, with a high quality of service factors like, no data redundancy, no resource limitations[17]. Although many of these routing techniques look promising, there are still many challenges that need to be solved in the sensor networks.

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APPENDICES

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